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(54) **REDUCING NOISE AND ARTIFACTS IN AN IMAGE**

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**H04N 1/58** (2006.01)

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348/701; 348/631; 348/627

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348/607, 621, 630, 631, 666, 701, 708, 627,  
348/253; 382/275, 268, 235; 375/240.27,  
375/240.25

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

6,856,704	B1 *	2/2005	Gallagher et al. ....	382/263
7,076,113	B2 *	7/2006	Le Dinh .....	382/261
2003/0215153	A1 *	11/2003	Gindele et al. ....	382/254
2005/0078872	A1	4/2005	Samadani et al.	
2005/0244061	A1	11/2005	Shaked et al.	
2005/0244075	A1	11/2005	Shaked et al.	

**OTHER PUBLICATIONS**

Netravali, A., "Noise Removal from Chrominance Components of a Color Television Signal", IEEE Transactions on Communications, vol. Com-26, No. 8, Aug. 1978.

Samadani, R., "Characterizing and Estimating Block DCT Image Compression Quantization Parameters", HP Laboratories Palo Alto, HPL-2005-190, Oct. 20, 2005 Internal Accession Date.

Samadani, R. et al., "Deringing and Deblocking DCT Compression Artifacts with Efficient Shifted Transforms", HP Labs Palo Alto, Imaging Technologies Dept., downloaded Apr. 17, 2006.

Tomasi, C., et al., "Bilateral Filtering for Gray and Color Images", downloaded Apr. 17, 2006.

\* cited by examiner

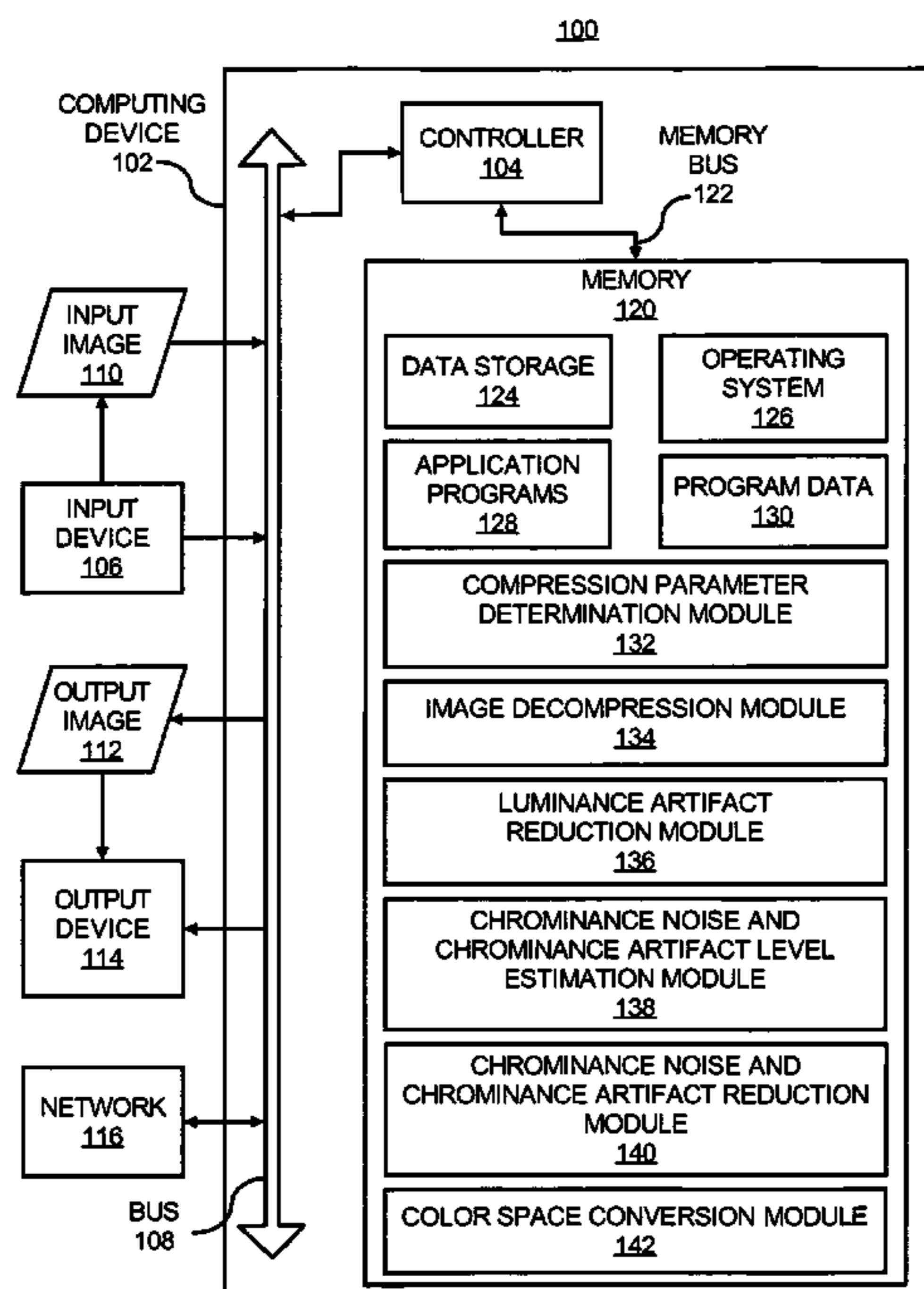
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(57) **ABSTRACT**

In a method of processing an input image, compression parameters of the input image are determined and luminance artifacts in the input image are reduced to obtain an improved luminance component of the input image, where the determined compression parameters guide the luminance artifact reduction. In addition, a chrominance noise and chrominance artifact level of the input image is estimated and a spatially-correlated chrominance noise and chrominance artifact of the input image is reduced with the improved luminance component, where the estimated chrominance noise and chrominance artifact level guide the spatially-correlated chrominance noise and chrominance artifact reduction to obtain an improved chrominance component of the input image. Moreover, an output image having the improved luminance component and the improved chrominance component is outputted.

**20 Claims, 5 Drawing Sheets**



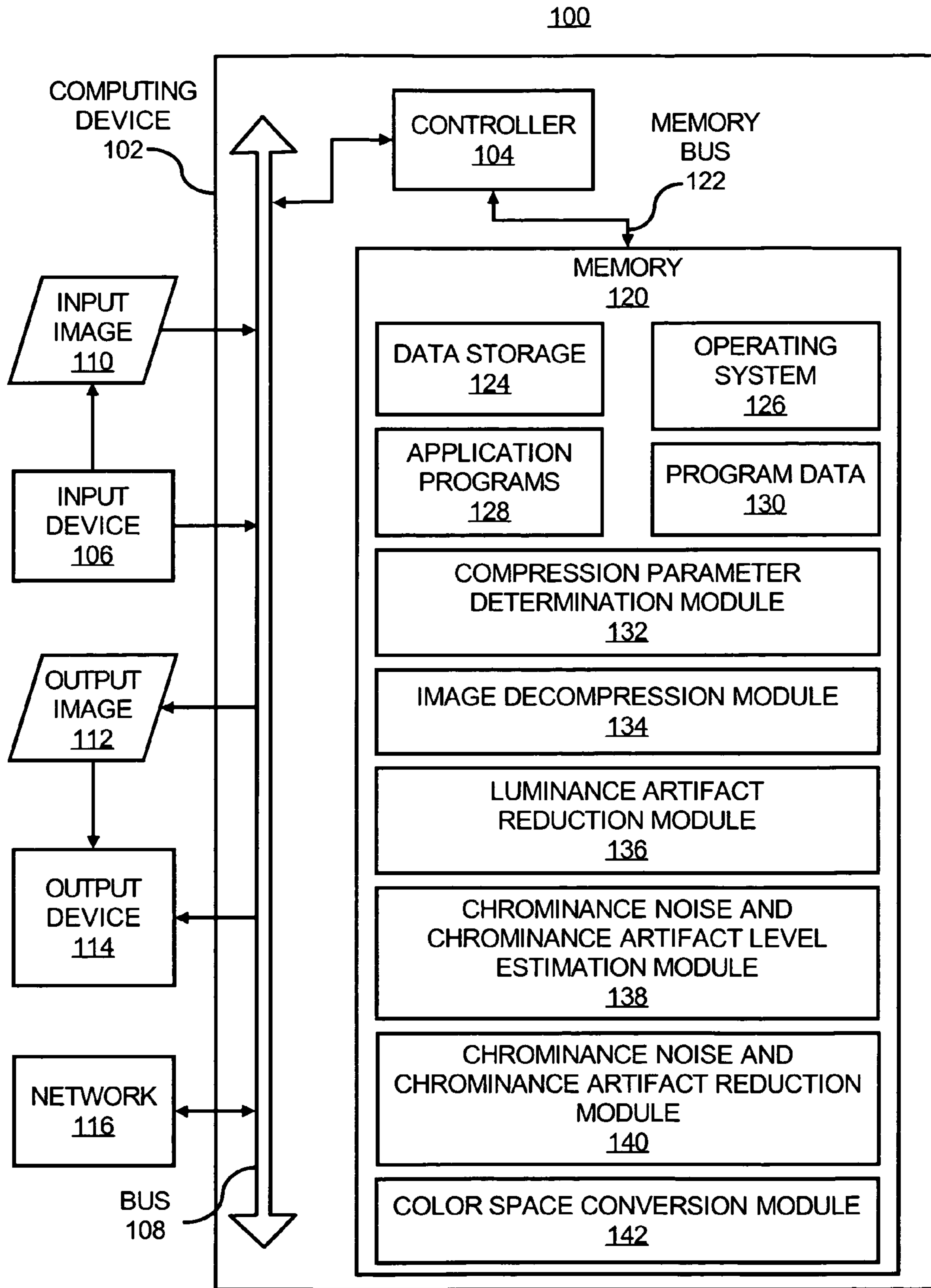
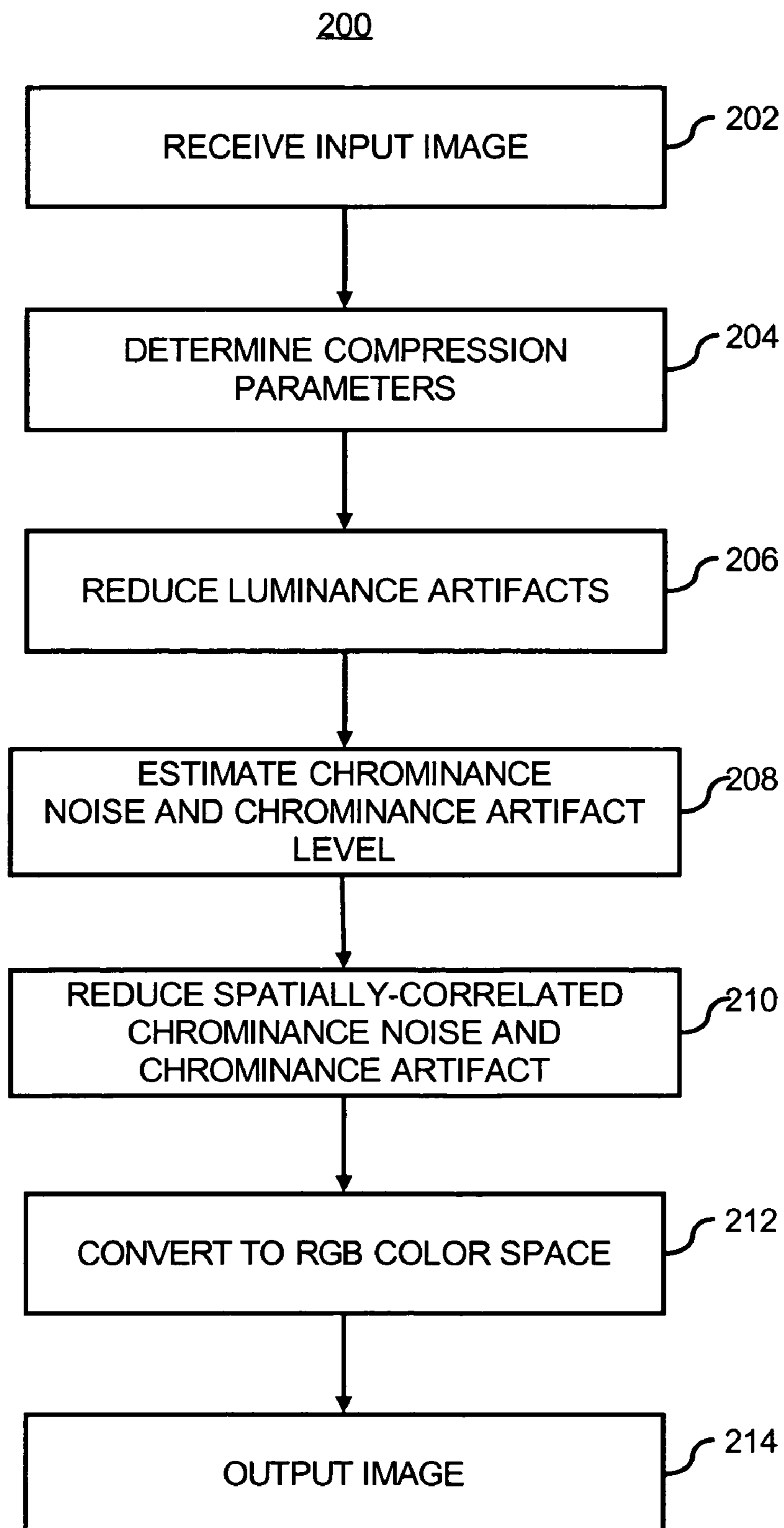


FIG. 1

**FIG. 2**

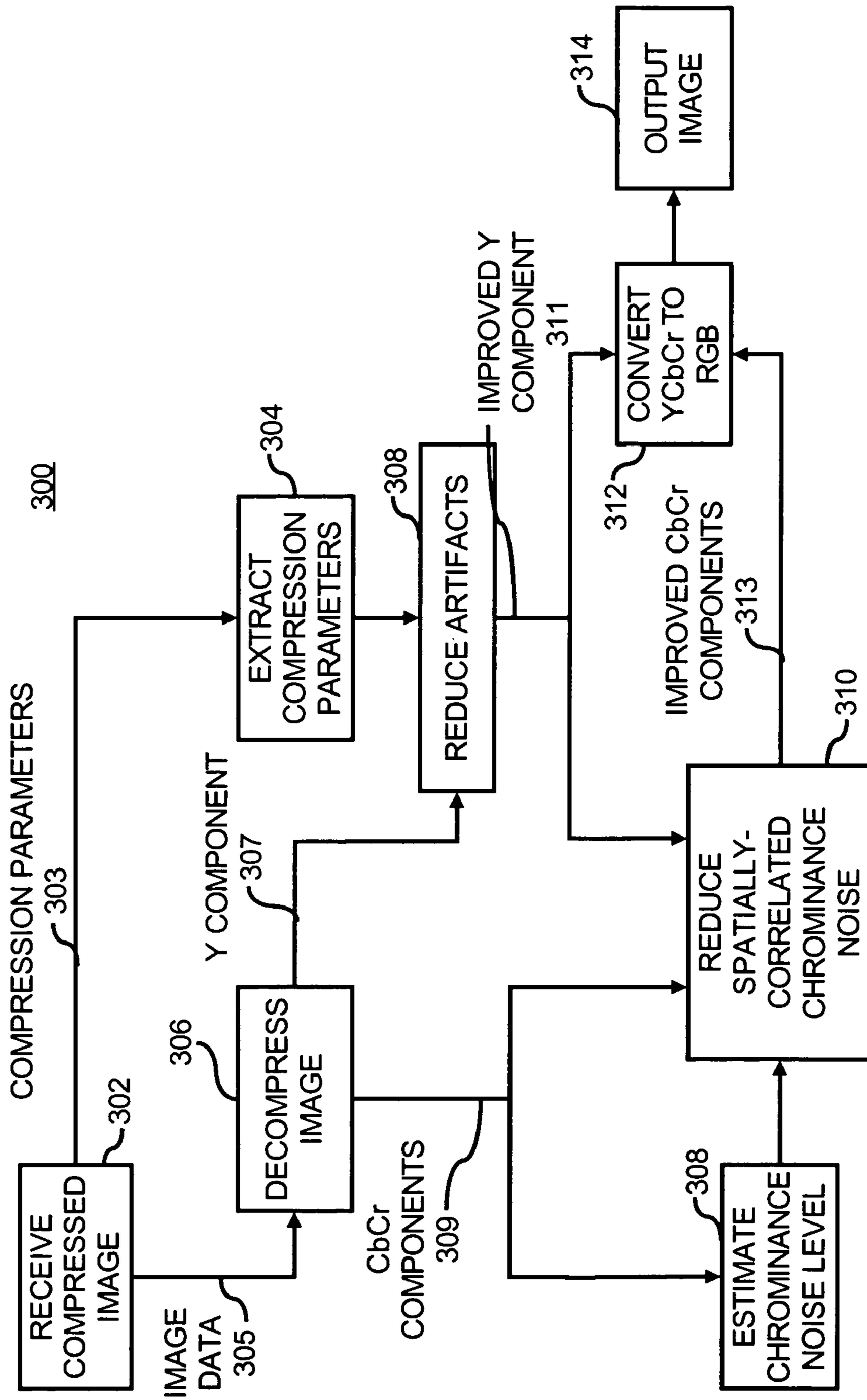


FIG. 3A

350

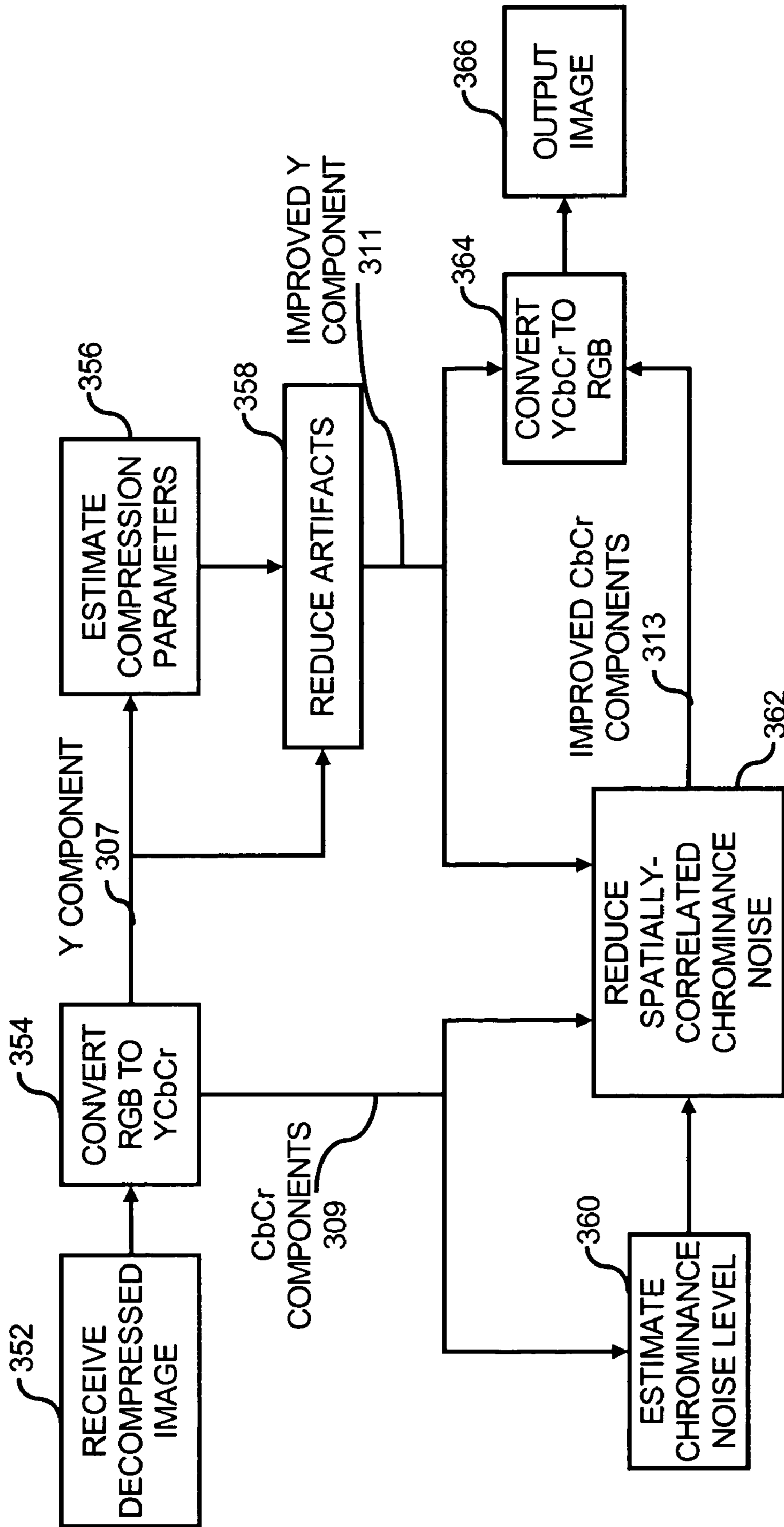


FIG. 3B



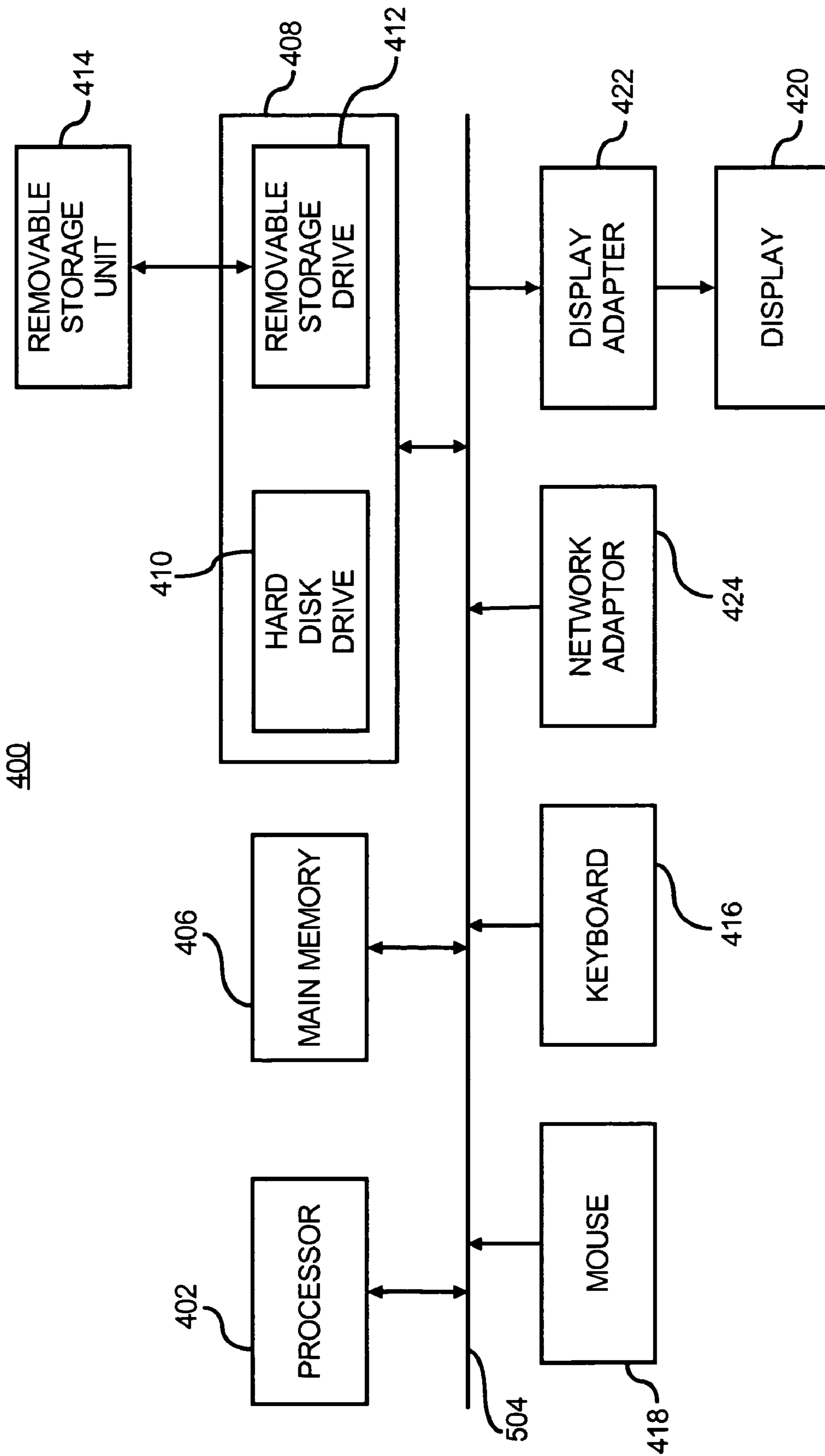


FIG. 4

## 1

**REDUCING NOISE AND ARTIFACTS IN AN  
IMAGE**

## BACKGROUND

Traditional digital images from low resolution sources, such as, cellular telephones, personal digital assistants and web sites typically have both compression artifacts and image noise. The compression artifacts often produce blocks and ringing, and the image noise often results in correlated luminance and chrominance errors. Images that contain both compression artifacts together with image noise are much harder to enhance than images containing only a single type of degradation. This is because estimating image noise levels is difficult for low-resolution images, and erroneous noise estimates in the luminance channel often result in insufficient luminance noise reduction or overly blurred images, and artifact reduction alone does not sufficiently reduce the strong chrominance noise (which is not necessarily due to compression) that is typically observed with these images.

In comparing the lower resolution images obtained from the above-described low resolution sources with higher resolution images, the lower resolution images typically have higher noise due to low quality CMOS image sensors. In addition, the lower resolution capture devices typically have lower cost, and hence lower quality optics, and often have a relatively high compression ratio. As such, the lower resolution images often have a relatively large number of visually objectionable artifacts, especially for images obtained in low light situations, which are typically more clearly visible when the images are enlarged.

Conventional techniques for improving the lower resolution images have included aggressive linear filtering. However, conventional aggressive linear filtering techniques often resulted in the introduction of visible saturation variations or excessive de-saturation of the image. Other challenges to conventional image enhancement techniques for low resolution images include the fact that many artifact reduction methods do not work reasonably well for chrominance channels because chrominance noise and artifact are not due solely to compression artifacts, but due to other image noise sources, and they are found to be extremely high for many of the low-resolution images. In addition, it is often relatively difficult to estimate the amount of noise and hence the denoising parameters for relatively small images. Moreover, estimating chrominance channel compression parameters is typically much more difficult than the luminance channel because of unknown subsampling factors and higher compression settings for chrominance.

## BRIEF DESCRIPTION OF THE DRAWINGS

Features of the present invention will become apparent to those skilled in the art from the following description with reference to the figures, in which:

FIG. 1 shows a block diagram of an image processing system, according to an embodiment of the invention;

FIG. 2 shows a flow diagram of a method of processing an input image, according an embodiment of the invention;

FIG. 3A shows a flow diagram of a method, which shows in greater detail the method depicted in FIG. 2 according to a first embodiment of the invention;

FIG. 3B shows a flow diagram of a method, which shows in greater detail the method depicted in FIG. 2 according to a second embodiment of the invention; and

## 2

FIG. 4 illustrates a computer system, which may be employed to perform various functions described herein, according to an embodiment of the invention.

## DETAILED DESCRIPTION

For simplicity and illustrative purposes, the present invention is described by referring to embodiments thereof. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent however, to one of ordinary skill in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

An input image may include one or both of compression artifacts and image noise. As described in greater detail herein below, the input image may be processed in various respects to substantially reduce or eliminate both of the compression artifacts and the image noise. In one regard, the input image may be processed such that the artifacts are reduced in the luminance channel and the image noise and artifacts are reduced in the chrominance channel. In addition, the artifact reduced luminance channel may operate as guidance for multi-resolution luminance-guided filtering of the chrominance channel.

The techniques disclosed herein are operable to reduce relatively high noise and artifacts in the chrominance channels by using the artifact reduced luminance channel as guidance for multi-resolution filtering in the chrominance channel. Thus, the chrominance noise and artifact may be reduced in a relatively aggressive manner substantially without blurring the image and may rely on relatively less accurate noise estimation techniques. The techniques disclosed herein may also be relatively robust to the errors in the noise variance estimation since these estimates may only be used to reduce chrominance noise and chrominance artifacts, where errors in the estimates are not as visible as they would be in the luminance channel. In addition, these techniques may be relatively robust to the estimation of compression parameters since these estimates may only be required for the luminance component artifact reduction.

Generally speaking, the compression artifact reduction parameters required in the luminance channel are fairly robust. In certain examples, the parameters are directly derived from compression parameters directly available from digital image files. Even in cases where the compression parameters require estimation, the parameters are simpler to estimate than chrominance compression parameters because there is no subsampling in the luminance components, and the quantization factors are typically smaller, making their estimation easier.

Also disclosed herein is an architecture that concurrently reduces compression artifacts and image noise. The combination is performed in a way that alleviates weaknesses of singularly applying either compression artifact reduction or image noise reduction. According to an example, the blocks for compression artifact reduction and image noise reduction may: 1) reduce compression artifacts effectively by processing only the luminance channel and 2) reduce the high noise and artifacts in the chrominance channel by using the artifact reduced luminance channel as guidance for multi-resolution noise filtering (in other words, the chrominance noise and chrominance artifact reduction may be more aggressive without blurring the image and may rely less on accurate noise estimation). In addition, the techniques disclosed herein are more robust to errors in the noise variance estimation since



these estimates are used only to reduce chrominance noise and chrominance artifacts and are more robust to estimation of compression parameters (required by some architectures) since they are only needed for the luminance component as compared with known image enhancement techniques.

With reference first, however, to FIG. 1, there is shown a block diagram of an image processing system 102 configured to process an input image, according to an example. It should be understood that the following description of the image processing system 100 is but one manner of a variety of different manners in which such an image processing system 100 may be configured and operated. In addition, it should be understood that the image processing system 100 may include additional components and that some of the components described may be removed and/or modified without departing from a scope of the image processing system 100. Moreover, it should be understood that some of the components described may not be implemented for each of the various image processing techniques disclosed herein.

Generally speaking, the image processing system 100 may be implemented to perform the various image processing techniques disclosed herein. As such, for instance, the image processing system 102 may comprise a platform through which the disclosed various image processing techniques may be performed to substantially reduce or eliminate both of the compression artifacts and the image noise in an input image.

The image processing system 100 is depicted as including a computing device 102, having a controller 104 configured to perform various image processing functions described herein. In one regard, the controller 104 may comprise a microprocessor, a micro-controller, an application specific integrated circuit (ASIC), and the like. The controller 104 may also be configured to perform other processing tasks, such as, the performance of other processing tasks of the computing device.

The controller 202 is depicted as being configured to receive information from an input device 106, such as, a keyboard, a touchpad, a mouse, a pen, a disk drive, an external memory, etc. As shown, inputs from the input device 106 may be communicated to the controller 104 through a bus 108 of the computing device 102, to which the input device 106 may be connected in any reasonably suitable known manner. A user may, for instance, use the input device 106 to input an image 110, or data pertaining to the input image 110, to be processed into the computing device 102. In addition, the controller 104 may store the information received through the input device 106, such as, an input image 110, in a memory 120. For instance, the input image 110 may be transferred into the memory 120 through a memory bus 122 and may be stored in a data storage 124 of the memory 120. In addition, the input image 110 may comprise a relatively low resolution image, such as those obtainable from cellular telephones, to a relatively high resolution image, such as those obtainable from digital cameras.

As described in greater detail herein below, the controller 104 may process the input image 110 to obtain an output image 112. The controller 104 may output the output image 112 through an output device 114 such as, a monitor, a printer, a disk drive, an external memory, etc., which may be connected to the bus 108 in an reasonably suitable known manner. In addition, or alternatively, the information communicated through the output device 114 may be communicated over a network 116, such that the information may be communicated to, for instance, another computing device (not shown). In this regard, the network 116 may comprise a local

area network, the Internet, and the like. In addition, the controller 104 may also receive the input image 110 through the network 116.

The memory 120 may generally be configured to provide storage of software, algorithms, and the like, that provide the functionality of the controller 104. By way of example, the memory 120 may store an operating system 126, application programs 128, program data 130, and the like. In this regard, the memory 120 may be implemented as a combination of volatile and non-volatile memory, such as DRAM, EEPROM, MRAM, flash memory, and the like. In addition, or alternatively, the memory 120 may comprise a device configured to read from and write to a removable media, such as, a floppy disk, a CD-ROM, a DVD-ROM, or other optical or magnetic media.

The memory 120 is also depicted as storing a compression parameter determination module 132, an image decompression module 134, a luminance artifact reduction module 136, a chrominance noise and chrominance artifact level estimation module 138, a chrominance noise and chrominance artifact reduction module 140, and a color space conversion module 142. The controller 104 may implement the modules 132-142 in processing an input image 110. Some or all of the modules 132-142 depicted the computing device 102 may comprise software which the controller 104 may implement. In addition, or alternatively, some or all of the modules 132-142 may comprise one or more hardware devices that may be controlled by the controller 104.

In either respect, the various manners in which the controller 104 may implement the modules 132-142 are described in detail herein below with respect to FIGS. 2, 3A, and 3B. More particularly, FIG. 2 provides an overview of the enhancement techniques disclosed herein, which is generic to the flow diagrams depicted in FIGS. 3A and 3B. In addition, FIGS. 3A and 3B provide more detailed descriptions of the flow diagram depicted in FIG. 2, according to two examples.

Generally speaking, FIGS. 2, 3A, and 3B show respective flow diagrams of methods 200, 300, and 350 of processing an input image, according to various examples. It is to be understood that the following descriptions of the methods 200, 300, 350 are a few manners of a variety of different manners in which an input image may be processed according to examples of the invention. It should also be apparent to those of ordinary skill in the art that the methods 200, 300, 350 represent generalized illustrations and that other steps may be added or existing steps may be removed, modified or rearranged without departing from the scopes of the methods 200, 300, 350.

With reference first to FIG. 2, there is shown a flow diagram of a method 200 of processing an input image 110, according to a first example. As shown, an input image 110 may be received at step 202. The input image 110 may comprise a compressed image or a decompressed image. As described below, the input image 110 may be processed in different manners depending upon whether the input image 110 comprises a compressed image or a decompressed image. A technique for processing a compressed input image 110 is described with respect to the flow diagram depicted in FIG. 3A and a technique for processing a decompressed input image 110 is described with respect to the flow diagram depicted in FIG. 3B. First, however, a description of method 200, which is generic to both of the flow diagrams depicted in FIGS. 3A and 3B, is provided.

Referring back to FIG. 2, the controller 104 may implement the compression parameter determination module 132 to determine the compression parameters of the input image 110, as indicated at step 204. Various manners in which the



compression parameter determination module **132** may be implemented to determine the compression parameters are described in greater detail with respect to FIGS. **2A** and **2B**.

At step **206**, the controller **104** may implement the luminance artifact reduction module **136** to reduce luminance artifacts contained in the input image **110** and obtain an improved luminance component of the input image **110**. The controller **104** may use the compression parameters determined at step **204** to guide the luminance artifact reduction at step **206**. The luminance artifacts and the chrominance artifacts may include artifacts caused by compression of the input image **110**, such as, blocks, ringing, and the like.

In any regard, the luminance artifact reduction module **136** may be implemented to reduce the luminance artifacts at step **206** through use of any reasonably suitable known artifact reduction technique. An artifact reduction technique suitable for use by the luminance artifact reduction module **136** may be found in copending and commonly assigned U.S. Patent Publication No. 2005/0078872 (U.S. patent application Ser. No. 10/683,322), filed on Oct. 10, 2003, and entitled "Reducing Artifacts in Compressed Images", the disclosure of which is hereby incorporated by reference in its entirety.

The controller **104** may also implement the chrominance noise and chrominance artifact level estimation module **138** to estimate the chrominance noise and chrominance artifact level of the input image **110**, as indicated at step **208**. The chrominance noise and chrominance artifact level estimation module **138** may be implemented to estimate the chrominance noise and chrominance artifact level at step **208** through use of any reasonably suitable known chrominance noise and chrominance artifact level estimation technique. Examples of suitable noise level estimation techniques are disclosed in copending and commonly assigned U.S. patent application Ser. No. 11/388,152, entitled "A Method for Noise Estimation Based on Order Statistics of Local Variances", filed on Mar. 22, 2006, U.S. patent application Ser. No. 11/129,924, entitled, "Estimating Image Compression Quantization Parameter Values", filed on May 16, 2005, and U.S. Patent Publication Serial No. 2005/0244075 (U.S. patent application Ser. No. 10/835,969), entitled "System and Method for Estimating Image Noise", filed on Apr. 29, 2004, the disclosures of which are hereby incorporated by reference in their entireties.

At step **210**, the controller **104** may implement the chrominance noise and chrominance artifact reduction module **140** to reduce the spatially-correlated chrominance noise and chrominance artifacts of the input image **110** and thereby obtain an improved chrominance component of the input image **110**. The controller **104** may, for instance, use the improved luminance component of the input image **110** obtained at step **206** and the chrominance noise and chrominance artifact level estimated at step **208** to reduce the spatially-correlated chrominance noise and chrominance artifacts at step **210**. By way of example, the chrominance noise and chrominance artifact reduction module **140** may employ a multi-resolution luminance-guided chrominance filtering technique to reduce the spatially-correlated chrominance noise and chrominance artifacts.

In other words, the chrominance noise and chrominance artifact reduction module **140** may be implemented to construct a multi-resolution image pyramid of the input image **110**. The top level of the image pyramid may have the lowest spatial resolution and the lowest level of the image pyramid may have to highest spatial resolution. The levels of the image pyramid may be formed, for instance, through smoothing and downsampling to create the images with the lower resolutions as disclosed in copending and commonly assigned U.S.

patent application Ser. No. 11/174,686, filed on Jul. 5, 2005, entitled "Multi-Resolution Processing of Digital Signals", the disclosure of which is hereby incorporated by reference in its entirety.

As disclosed in the Ser. No. 11/174,686 application, a feature-preserving noise filtering operation is performed on the top level and the difference between the original top level and the denoised top level is computed. This difference may be interpolated and subtracted from the next lower level, which has a relatively higher spatial resolution, to thereby remove the low-frequency (correlated) noise component at the next lower level with higher spatial resolution. A feature-preserving denoising operation is then performed on that level. This process may be repeated until the lowest level, which has the highest spatial resolution, is denoised.

Similarly to the disclosure contained in the Ser. No. 11/174,686 application, the controller **104** may implement the chrominance noise and chrominance artifact reduction module **140** to construct a multi-resolution image pyramid of the input image **110**. However, the noise filtering operations performed at each of the levels may be performed through a luminance-guided chrominance filtering technique. In other words, the improved luminance terms obtained at step **206** may be exploited by the chrominance noise and chrominance artifact reduction module **140** to improve the chrominance level of the top level, which has the lowest spatial resolution. The chrominance noise and chrominance artifact reduction module **140** may implement any reasonably suitable known luminance-guided chrominance filtering technique. An example of a suitable filtering technique is disclosed in the article "Noise Removal From Chrominance Components of a Color Television Signal", by Arun N. Netravali, printed in IEEE Transactions on Communication, Vol. Com-26, NO. 8, August 1978, the disclosure of which is hereby incorporated by reference in its entirety.

As another example, the controller **104** may implement the chrominance noise and chrominance artifact reduction module **140** to reduce the spatially-correlated chrominance noise and chrominance artifacts through use of a bilateral filter. The bilateral filter is a non-linear filter introduced by Tomasi and Manduchi, which is used for selective denoising without blurring edges. The bilateral filter is based upon the idea of modifying weights of a convolution mask in an image dependent manner, based upon intensity differences between the pixel under consideration and its neighbors. In a conventional bilateral filter, the signal  $y(i)$  is filtered with the following formula:

$$y^*(i) = \frac{1}{\sum_j g(y(i) - y(i-j)) \cdot h(j)} \sum_j y(i-j) \cdot g(y(i-j) - y(i)) \cdot h(j), \text{ where } h(\cdot) \text{ is the}$$

Equation (1)

convolution kernel,  $y^*(\cdot)$  is the denoised output,  $i, j$  are pixel indices and  $g(\cdot)$  is the photometric distance term used for selective denoising without blurring edges.

According to an example, the bilateral filter in Equation (1) may be modified such that the chrominance filtering may be more aggressive without blurring the image details. The chrominance noise and chrominance artifact reduction module **140** may use the improved luminance component as an additional input to obtain an improved chrominance component (Cb/Cr) at step **210**. Thus, for instance, when denoising



7

the chrominance component  $cb(i)$ , the  $g(y(i)-y(i-j))$  term in Equation (1) is replaced with  $g_2(cb(i)-cb(i-j), y^*(i)-y^*(i-j), \lambda)$ , as follows:

Equation (2)

$$cb^*(i) = \frac{1}{\sum_j g(cb(i-j) - cb(i), y^*(i-j) - y^*(i), \lambda)} \sum_j cb(i-j) \cdot g(cb(i-j) - cb(i), y^*(i-j) - y^*(i), \lambda) \cdot h(j)$$

where  $\lambda$  is the weighting between luminance guidance and chrominance guidance. In addition, a Gaussian function, such as,  $g(x, y, \lambda, k) = \exp(k(x^2 + \lambda y^2))$ , where  $k < 0$ , is an example of a suitable  $g$  function.

In either of the examples above, the chrominance noise and chrominance artifact reduction module **140** may be implemented to perform a luminance-guided chrominance filtering operation at the top level of the image pyramid to obtain an improved chrominance component. According to an example, for instance, the noise and artifact level for the top level of the image pyramid may optionally be estimated prior to multi-resolution luminance-guided chrominance filtering. In addition, a difference between the original chrominance component and the improved chrominance component for the top level may be computed. This difference may be interpolated and subtracted from the next lower level, which has a relatively higher spatial resolution, to thereby remove the correlated low-frequency noise component at that higher resolution level. A luminance-guided chrominance filtering operation is performed at that next level. The noise and artifact level may optionally be estimated for this level prior to performance of the luminance chrominance filtering operation for this level. In addition, the chrominance reduction and the optional noise and artifact estimation may repeat this process until the lowest level, which has the highest spatial resolution, is improved, to thereby obtain an improved chrominance component of the input image **110**.

At step **212**, the controller **104** may implement the color space conversion module **142** to convert the improved chrominance component and the improved luminance component into the Red-Green-Blue (RGB) color space. In one respect, the color space conversion module **142** may operate to combine the improved chrominance component and the improved luminance component in the RGB color space to produce the output image **112**.

The controller **104** may output the output image **112**, as indicated at step **214**. As discussed above, the output image **112** may be outputted to at least one of an output device **114** and a network **116**.

With reference now to the method **300** depicted in FIG. 3A, the method **200** depicted in FIG. 2 is shown in greater detail, according to a first example. In addition, the method **300** illustrates one manner in which the method **200** may be implemented when the input image **110** comprises a compressed image, such as a JPEG image. As such, a compressed input image **110** may be received at step **302**.

8

The controller **104** may implement the compression parameter determination module **132** to extract compression parameters **303** from the compressed input image **110**, as indicated at step **304**. More particularly, for instance, the compression parameter determination module **132** may be implemented to extract the compression parameters **303** directly from the compressed input image **110**, in any reasonably suitable known manner.

In addition, at step **306**, the controller **104** may implement the image decompression module **134** to decompress the compressed input image **110**. As shown, the controller **104** may implement the image decompression module **134** to separate data **305** pertaining to the compressed input image **110** into a luminance (Y) component **307** and chrominance (CbCr) or color components **309**.

At step **308**, the controller **104** may use the compression parameters extracted at step **304** and the luminance (Y) component **307** separated from the image data at step **306** as inputs to the luminance artifact reduction module **136** to thereby reduce luminance artifacts in the compressed input image **110**. In addition, the controller **104** may reduce luminance artifacts in the compressed input image **110** as described above with respect to step **206** (FIG. 2) to obtain an improved luminance (Y) component **311**.

The controller **104** may implement the chrominance noise and chrominance artifact level estimation module **138** to estimate the chrominance noise and chrominance artifact level of the compressed input image **110**, using the chrominance components **309** extracted by the image decompression module **134**, at step **308**. The chrominance noise and chrominance artifact level estimation module **138** may operate as described above with respect to step **208** (FIG. 2). In addition, at step **310**, the controller **104** may implement the chrominance noise and chrominance artifact reduction module **140** to perform the multi-resolution luminance-guided chrominance filtering to obtain improved chrominance components **313** in manners described above with respect to step **210** (FIG. 2).

At step **312**, the controller **104** may implement the color space conversion module **142** to convert the improved chrominance component **313** and the improved luminance component **311** into the Red-Green-Blue (RGB) color space. In one respect, the color space conversion module **142** may operate to combine the improved chrominance component **313** and the improved luminance component **311** in the RGB color space to produce the output image **112**. In addition, at step **314**, the controller **104** may output the output image **112**, through, for instance, at least one of an output device **114** and a network **116**.

Turning now to the method **350** depicted in FIG. 3B, the method **200** depicted in FIG. 2 is shown in greater detail, according to a second example. In addition, the method **350** illustrates one manner in which the method **200** may be implemented when the input image **110** comprises a decompressed image. As such, a decompressed input image **110** may be received at step **352**.

At step **354**, the controller **104** may implement the color space conversion module **142** to convert the decompressed input image **110** from the RGB color space to the luminance-chrominance (YCbCr) color space. In addition, the controller **104** may implement the compression parameter determination module **132** to estimate compression parameters from the luminance (Y) component **307** of the decompressed input image **110** in any reasonably suitable manner. An example of a suitable compression estimation technique is disclosed in the article entitled "Characterizing and Estimating Block DCT Image Compression Quantization Parameters", authored by Ramin Samadani, and published in the Asilomar



Conference on Signals, Systems, and Computers, 30 October 2 Nov. 2005, Pacific Grove, Calif., the disclosure of which is hereby incorporated by reference in its entirety.

The controller **104** may also implement the luminance artifact reduction module **136** to obtain an improved luminance (Y) component **311**, at step **358**. The controller **104** may implement the luminance artifact reduction module **136** to reduce luminance artifacts in the decompressed input image **110** in any reasonably suitable manner. An example of a suitable compression artifact reduction technique is disclosed in the article entitled “Deringing and Deblocking DCT Compression Artifacts with Efficient Shifted Transforms”, authored by Ramin Samadani et al., and published in the IEEE International Conference on Image Processing, October 2004, Singapore.

The controller **104** may implement the chrominance noise and chrominance artifact level estimation module **138** to estimate the chrominance noise and chrominance artifact level of the decompressed input image **110**, using the chrominance components **309** extracted by the color space conversion module **134**, at step **360**. The chrominance noise and chrominance artifact level estimation module **138** may operate as described above with respect to step **208** (FIG. 2). In addition, at step **362**, the controller **104** may implement the chrominance noise and chrominance artifact reduction module **140** to perform the multi-resolution luminance-guided chrominance filtering to obtain improved chrominance components **313** in manners described above with respect to step **210** (FIG. 2).

At step **364**, the controller **104** may implement the color space conversion module **142** to convert the improved chrominance component **313** and the improved luminance component **311** into the Red-Green-Blue (RGB) color space. In one respect, the color space conversion module **142** may operate to combine the improved chrominance component **313** and the improved luminance component **311** in the RGB color space to produce the output image **112**. In addition, at step **314**, the controller **104** may output the output image **112**, through, for instance, at least one of an output device **114** and a network **116**.

The operations set forth in the methods **200**, **300**, and **350** may be contained as a utility, program, or subprogram, in any desired computer accessible medium. In addition, the methods **200**, **300**, and **400** may be embodied by a computer program, which may exist in a variety of forms both active and inactive. For example, it can exist as software program(s) comprised of program instructions in source code, object code, executable code or other formats. Any of the above can be embodied on a computer readable medium, which include storage devices and signals, in compressed or uncompressed form.

Exemplary computer readable storage devices include conventional computer system RAM, ROM, EPROM, EEPROM, and magnetic or optical disks or tapes. Exemplary computer readable signals, whether modulated using a carrier or not, are signals that a computer system hosting or running the computer program can be configured to access, including signals downloaded through the Internet or other networks. Concrete examples of the foregoing include distribution of the programs on a CD ROM or via Internet download. In a sense, the Internet itself, as an abstract entity, is a computer readable medium. The same is true of computer networks in general. It is therefore to be understood that any electronic device capable of executing the above-described functions may perform those functions enumerated above.

FIG. 4 illustrates a computer system **400**, which may be employed to perform the various functions of the computing

device **102** described herein above, according to an example. In this respect, the computer system **400** may be used as a platform for executing one or more of the functions described hereinabove with respect to the computing device **102**.

The computer system **400** includes a processor **402**, which may comprise the controller **104**, and which may be used to execute some or all of the steps described in the methods **200**, **300**, and **350**. Commands and data from the processor **402** are communicated over a communication bus **404**, such as the bus **108**. The computer system **400** also includes a main memory **406**, such as a random access memory (RAM), where the program code for, for instance, the controller **104**, may be executed during runtime, and a secondary memory **408**. The secondary memory **408** includes, for example, one or more hard disk drives **410** and/or a removable storage drive **412**, representing a floppy diskette drive, a magnetic tape drive, a compact disk drive, etc., where a copy of the program code for the processing of images may be stored.

The removable storage drive **410** reads from and/or writes to a removable storage unit **414** in a well-known manner. User input and output devices **106**, **114** (FIG. 1) may include a keyboard **416**, a mouse **418**, and a display **420**. A display adaptor **422** may interface with the communication bus **404** and the display **420** and may receive display data from the processor **402** and convert the display data into display commands for the display **420**, which may be used to display the output image **112**. In addition, the processor **402** may communicate over a network, for instance, the Internet, LAN, etc., through a network adaptor **424**.

It will be apparent to one of ordinary skill in the art that other known electronic components may be added or substituted in the computer system **400**.

In addition, the computer system **400** may include a system board or blade used in a rack in a data center, a conventional “white box” server or computing device, etc. Also, one or more of the components in FIG. 4 may be optional (for instance, user input devices, secondary memory, etc.).

What has been described and illustrated herein is a preferred embodiment of the invention along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration only and are not meant as limitations. Those skilled in the art will recognize that many variations are possible within the scope of the invention, which is intended to be defined by the following claims—and their equivalents—in which all terms are meant in their broadest reasonable sense unless otherwise indicated.

What is claimed is:

1. A method of processing an input image, said method comprising:
  - determining compression parameters of the input image;
  - reducing luminance artifacts in the input image to obtain an improved luminance component of the input image, wherein the determined compression parameters guide the luminance artifact reduction;
  - estimating a chrominance noise and chrominance artifact level of the input image;
  - reducing a spatially-correlated chrominance noise and chrominance artifacts of the input image with the improved luminance component, wherein the estimated chrominance noise and chrominance artifact level guide the spatially-correlated chrominance noise and chrominance artifact reduction to obtain an improved chrominance component of the input image; and
  - outputting an output image having the improved luminance component and the improved chrominance component.



**11**

2. The method according to claim 1, further comprising:  
converting the improved luminance component and the  
improved chrominance component to an RGB color  
space; and

wherein outputting the output image further comprises  
outputting the output image in the RGB color space.

3. The method according to claim 1, wherein reducing the  
spatially-correlated chrominance noise and chrominance  
artifacts further comprises constructing a multi-resolution  
image pyramid of the input image and applying multi-reso-  
lution luminance-guided chrominance filtering at each level  
of the image pyramid to obtain an improved chrominance  
component.

4. The method according to claim 3, further comprising  
computing a difference between the improved chrominance  
component and an inputted chrominance component at each  
level of the image pyramid, and interpolating and subtracting  
the difference from a next lower level of the image pyramid  
repeatedly to thereby obtain the improved chrominance com-  
ponent of the input image.

5. The method according to claim 1, wherein the input  
image comprises a compressed image, and wherein determin-  
ing compression parameters of the input image further com-  
prises extracting the compression parameters from the com-  
pressed input image.

6. The method according to claim 5, further comprising:  
decompressing the compressed input image to obtain a  
luminance component and a chrominance component;  
and

wherein estimating a chrominance noise and chrominance  
artifact level further comprises estimating the chromi-  
nance noise and chrominance artifact level based upon  
the chrominance component.

7. The method according to claim 6, wherein reducing a  
spatially-correlated chrominance noise and chrominance  
artifacts further comprises reducing the spatially-correlated  
chrominance noise and chrominance artifacts based upon the  
chrominance component, the estimated chrominance noise  
and chrominance artifact level, and the improved luminance  
component.

8. The method according to claim 1, wherein the input  
image comprises a decompressed image, and wherein deter-  
mining compression parameters of the input image further  
comprises estimating compression parameters from a lumi-  
nance component of the decompressed input image.

9. The method according to claim 8, further comprising:  
converting the decompressed input image from an RGB  
color space to a YCbCr color space having a luminance  
component and a chrominance component; and

wherein reducing luminance artifacts in the input image  
further comprises using the luminance component and  
the estimated compression parameters to obtain the  
improved luminance component.

10. The method according to claim 9, wherein estimating a  
chrominance noise and chrominance artifact level further  
comprises estimating the chrominance noise and chromi-  
nance artifact level based upon the chrominance component  
and wherein reducing a spatially-correlated chrominance  
noise and chrominance artifacts further comprises reducing  
the spatially-correlated chrominance noise and chrominance  
artifacts based upon the chrominance component, the esti-  
mated chrominance noise and chrominance artifact level, and  
the improved luminance component.

11. A system for processing an input image, said system  
comprising:

- a compression parameter determination module;
- a luminance artifact reduction module;

**12**

a chrominance noise and chrominance artifact level esti-  
mation module;

a chrominance noise and chrominance artifact reduction  
module;

a controller for implementing the compression parameter  
determination module to determine compression param-  
eters of the input image, for implementing the luminance  
artifact reduction module to use the determined com-  
pression parameters to obtain an improved luminance  
component of the input image, for implementing the  
chrominance noise and chrominance artifact level esti-  
mation module to estimate a chrominance noise and  
chrominance artifact level of the input image, and for  
implementing the chrominance noise and chrominance  
artifact reduction module to use the improved luminance  
component and the estimated chrominance noise and  
chrominance artifact level to obtain an improved  
chrominance component of the input image; and

a device for outputting an output image having the  
improved luminance component and the improved  
chrominance component.

12. The system according to claim 11, further comprising:  
a color space conversion module, wherein the controller is  
configured to implement the color space conversion  
module to convert the input image between a RGB color  
space and luminance-chrominance color space.

13. The system according to claim 11, wherein the control-  
ler is further configured to implement the chrominance noise  
and chrominance artifact reduction module to construct a  
multi-resolution image pyramid of the input image, apply  
multi-resolution luminance-guided chrominance filtering at  
each level of the image pyramid to obtain an improved  
chrominance component at each level, determine a difference  
between an inputted chrominance component and the  
improved chrominance component at each level, and repeat-  
edly interpolate and subtract the difference from a next lower  
level of the image pyramid to thereby obtain the improved  
chrominance component of the input image.

14. The system according to claim 11, wherein the input  
image comprises a compressed image, and wherein the con-  
troller is configured to implement the compression parameter  
determination module to extract compression parameters  
from the compressed input image.

15. The system according to claim 14, further comprising:  
an image decompression module, wherein the controller is  
configured to implement the image decompression  
module to decompress the compressed input image to  
obtain a luminance component and a chrominance com-  
ponent, and wherein the controller is further configured  
to implement the chrominance noise and chrominance  
artifact level estimation module to estimate the chromi-  
nance level of the decompressed input image based upon  
the chrominance component.

16. The system according to claim 15, wherein the control-  
ler is further configured to implement the chrominance noise  
and chrominance artifact reduction module to reduce the  
spatially-correlated chrominance noise and chrominance  
artifacts based upon the chrominance component, the esti-  
mated chrominance noise and chrominance artifact level, and  
the improved luminance component.

17. The system according to claim 11, wherein the input  
image comprises a decompressed image, and wherein the  
controller is further configured to implement the compression  
parameter determination module to estimate compression  
parameters from a luminance component of the decom-  
pressed input image.



**13**

**18.** The system according to claim **17**, wherein the controller is further configured to implement the luminance artifact reduction module to use the luminance component and the estimated compression parameters to obtain the improved luminance component.

**19.** The system according to claim **18**, wherein the controller is further configured to implement the chrominance noise and chrominance artifact reduction module to use the chrominance component, the estimated chrominance noise and chrominance artifact level, and the improved luminance component to obtain the improved chrominance component.

**20.** A non-transitory computer readable medium upon which is stored a computer program, said computer program implementing a method for processing an image when executed by a processor, said computer program comprising a set of instructions to:

- determine compression parameters of the input image;
- reduce luminance artifacts in the input image to obtain an improved luminance component of the input image,

**14**

wherein the determined compression parameters guide the luminance artifact reduction;

estimate a chrominance noise and chrominance artifact level of the input image;

reduce a spatially-correlated chrominance noise and chrominance artifacts of the input image with the improved luminance component, wherein the estimated chrominance noise and chrominance artifact level guiding the spatially-correlated chrominance noise and chrominance artifact reduction to obtain an improved chrominance component of the input image; and

output an output image having the improved luminance component and the improved chrominance component.

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